

# Long-Term Propensity-Matched Comparison of Fenestrated Endovascular Aneurysm Repair and Open Surgical Repair of Complex Abdominal Aortic Aneurysms

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## Abstract

**Purpose:** This study investigated the long-term outcomes of patients treated with fenestrated and branched endovascular aneurysm repair (F-BEVAR) or open surgical repair (OSR) for complex abdominal aortic aneurysms (c-AAAs). Complex abdominal aortic aneurysms are defined as aneurysms that involve the renal or mesenteric arteries and extend up to the level of the celiac axis or diaphragmatic hiatus but do not extend into the thoracic aorta. This study compares with a propensity-score matching the outcome of these procedures from 2 high-volume aortic centers. **Materials and Methods:** All patients with c-AAAs undergoing repair at 2 centers between January 2010 and June 2016 were included. The long-term imaging follow-up consisted in a yearly computed tomography angiography (CTA) in the F-BEVAR group. Yearly abdominal ultrasound examination and 5-year CTA were performed in the OSR group. The primary endpoints were long-term mortality, aneurysm-related mortality, and chronic renal decline (CRD), defined as estimated glomerular filtration rate reduction to  $<60$  mL/min/1.73 m<sup>2</sup> or  $>20\%$ /de novo dependence on permanent dialysis in patients with normal or abnormal preoperative renal function, respectively. Secondary endpoints included aortic-related reinterventions, target vessel occlusion, proximal aorta degeneration, access-related complications, graft infection, and the composite endpoint of clinical failure during follow-up. **Results:** After 1:1 propensity matching, 102 consecutive patients who underwent F-BEVAR and OSR, respectively, were included. The median follow-up was 67 months. There was no significant difference in long-term overall mortality (40.2% vs 36.3%;  $p=0.40$ ) and aneurysm-related mortality (6.8% vs 5.8%;  $p=0.30$ ), in the F-BEVAR and OSR groups, respectively. During follow-up, late renal function decline occurred in 27 (27.8%) versus 46 patients (47.4%) in the F-BEVAR and OSR groups, respectively ( $p<0.01$ ). During follow-up, 23 reinterventions (23.5%) were performed in the F-BEVAR group, and 5 (5.1%) in the OSR group ( $p<0.01$ ). **Conclusions:** No differences in overall and aneurysm-related mortality were observed. Chronic renal decline was significantly higher after OSR, while the reintervention rate was higher in the F-BEVAR group. These long-term results reflect the outcomes of a complex procedure performed by a single experienced operator in 2 high-volume centers, and followed with a strict surveillance imaging follow-up.

## Clinical Impact

Nowadays, F-BEVAR and OSR are considered two established techniques for the treatment of c-AAA. However, long-term comparative outcomes are not well studied, and concerns may rise in terms of durability of the repair, risk of reinterventions and late chronic renal decline. The present study showed, with a median follow-up  $>5$  years, no differences in overall and aneurysm-related mortality. Chronic renal decline was significantly higher after OSR, while the reintervention rate was higher in the endovascular group. To achieve the best possible long-term outcomes, both techniques should be performed in high volume aortic centres, tailored to the patient, and with an adequate surveillance imaging.

## Keywords

open repair, FEVAR, BEVAR, complex abdominal aortic aneurysm, personalized medicine

## Introduction

Complex abdominal aortic aneurysms (c-AAAs) include juxtarenal, pararenal, paravisceral, and extent IV thoracoabdominal aortic aneurysm (TAAA).<sup>1,2</sup> Open surgical repair (OSR) has been considered the standard of care for c-AAA, but fenestrated and branched endovascular aortic repair (F-BEVAR) currently represents an effective and safe alternative.<sup>1,3,4</sup> However, in the literature, there is paucity of good quality evidence supporting the management of c-AAA.

Complex abdominal aortic aneurysm necessitates interrenal, supra-renal, and sometimes supra-celiac proximal clamping for OSR with infra-renal reconstruction and occasionally additional revascularization of the renal and/or visceral arteries. Transient renal ischemia owing to renal artery clamping is the essential feature of OSR for c-AAA in the postoperative time and might affect long-term renal function and overall prognosis.<sup>5-7</sup>

Comparatively, the need for more frequent postoperative computed tomography angiography (CTA) completion in the follow-up with repeated exposure to contrast medium, the rate of reintervention due to bridging stents/stent-graft-related complications, such as endoleaks (ELs) and fenestration/branch instability, might affect long-term outcomes after F-BEVAR.<sup>8-10</sup>

The impact of these 2 approaches has been poorly compared specifically in the long-term with regards to overall survival and complications, and particularly the analysis of renal function decline.

The aim of this study was to investigate long-term outcomes in a propensity-score-matched series of patients treated with F-BEVAR and OSR for c-AAA in 2 aortic high-volume centers.

## Materials and Methods

### Study Population

This multicenter retrospective study analyzes the long-term outcomes of a propensity-matched cohort of consecutive patients with complex AAA prospectively collected between January 2010 and June 2016 from 2 different high-volume aortic centers in Lille (France) and Rome (Italy). Complex AAAs are defined as aneurysms that involve the renal or mesenteric arteries and extend up to the level of the

celiac axis or diaphragmatic hiatus but do not extend into the thoracic aorta.<sup>1</sup>

Patients were selected according to the clinical practice of the participating centers. During the study period, no F-BEVARs were performed in Rome, and OSRs were not collected in Lille. In this study, F-BEVARs and OSRs were performed by a single experienced operator without the learning-curve bias.

The long-term follow-up was prospectively collected, including all patients previously enrolled in a similar preliminary study comparing mid-term outcomes.<sup>3</sup> The data were analyzed and reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.<sup>11</sup> The study was performed in accordance with the Institutional Ethics Committee rules, and individual consent for this retrospective analysis was waived. All patients provided consent for intervention. ClinicalTrials.gov Identifier: NCT05247944. Institutional Review Board ID: 1843.

### Operative Techniques

**Open surgery repair.** The retroperitoneal exposure of the aorta was achieved through an oblique incision from the tip of the eleventh rib to the lateral rectus border at the paraumbilical level. The anatomic access to the aorta was completed with the position of the left kidney (anterior or posterior) during the procedure, depending on the level of aortic clamping and the left renal vein anatomy. Exposure of the proximal abdominal aorta was obtained by division of the left diaphragmatic crus. A transperitoneal approach was used less frequently.

When the procedure also included renal artery surgery, we performed a direct reimplantation or a bypass with an 8 mm Dacron graft interposition. In this situation, a selective perfusion of the renal arteries was achieved through the infusion of cold renal perfusion (lactated Ringer solution and mannitol 10%).

**F-BEVAR.** All patients in the F-BEVAR group were treated with custom-made stent grafts within the instructions for use from the manufacturer (Cook Medical, Bloomington, Ind). The procedures required bilateral femoral access. General anesthesia was used in all patients with an open arterial exposure or a percutaneous approach when feasible.

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No preoperative cerebrospinal fluid drainage was performed. The bridge between the fenestrations and their respective target vessels (TVs) was performed with a covered balloon-expandable stent (Advanta V12 [Atrium Medical Corporation, Hudson, NH] or BeGrafts [Bentley InnoMed, Hechingen, Germany]); relining with bare-metal stents (Luminex; Bard, Murray Hill, NJ) was selectively used in scenarios of kinking or to secure the bridging stent in the TVs. Directional branches were used if the aortic lumen was  $>45$  mm at the level of the origin of the TVs. Technical success was defined by placement of the aortic stent and all intended side branches, the absence of type I and type III ELs, and patent TVs.

### Follow-Up

Patients were observed with regular postoperative appointments. The long-term imaging follow-up consisted in a yearly CTA in the F-BEVAR group; yearly abdominal ultrasound examination and 5-year CTA were performed in the OSR group. The yearly abdominal ultrasound examination in the OSR group was performed according to the Institution surveillance protocol. In case of abnormal renal function (estimated glomerular filtration rate [eGFR]  $<60$  mL/min/1.73m<sup>2</sup>), the patient underwent CT without contrast associated with a contrast-enhanced ultrasound examination in both groups. Laboratory data with evaluation of renal function by eGFR were completed at 3, 6, and 12 months, and yearly thereafter. Survival assessment was completed after medical records review, and general partitioner's, patients', or siblings' contact by phone.

### Endpoints

The primary endpoints were overall mortality, aneurysm-related mortality, and chronic renal decline (CRD) during follow-up. Secondary endpoints included aortic-related reintervention, TV occlusion, proximal aorta degeneration, access-related complications, graft infection, and the composite endpoint of clinical failure rate during follow-up.

Aneurysm-related mortality was defined by any death that results from aneurysm rupture, aorta-related complications, or a complication of a secondary intervention.<sup>1</sup>

The estimated glomerular filtration rate was determined by the abbreviated Modification of Diet in Renal Disease study equation (eGFR [mL/min/1.73m<sup>2</sup>] =  $186 \times [\text{serum creatinine}]^{-1.154} \times [\text{age}]^{-0.203} \times [0.704 \text{ if female}] \times [1.210 \text{ if African American}]$ ).<sup>12</sup>

Preoperative renal function was estimated using the chronic kidney disease (CKD) staging system and stratified as normal (stages 1-2, eGFR  $\geq 60$  mL/min/1.73m<sup>2</sup>) and abnormal (stage 3-4, eGFR  $<60$  mL/min/1.73m<sup>2</sup>).

A postoperative deterioration of the eGFR by 25% within 1 week according to the RIFLE (Risk, Injury, Failure, Loss

of kidney function, and End-stage renal failure) classification was defined as acute kidney injury (AKI).<sup>13</sup>

CRD was defined in patients with normal (stages 1-2) preoperative renal function as a reduction in the eGFR to  $<60$  mL/min/1.73 m<sup>2</sup> during follow-up. In patients with abnormal function (stages 3-4) preoperatively, it was defined as an eGFR reduction of  $>20\%$  or de novo dependence on permanent dialysis.<sup>14</sup>

Patients in stage 5 (eGFR  $<15$  mL/min/1.73m<sup>2</sup> or dependent on renal replacement therapy) were excluded from the renal function analysis.

Target vessel (TV) included visceral arteries (celiac trunk and superior mesenteric artery [SMA]) and renal arteries. For the F-BEVAR group, all vessels targeted by fenestrations and directional branches were included.<sup>1</sup> For OSR, TVs were defined as all vessels in relation to the proximal clamping site, included in proximal beveled anastomosis and/or directly revascularized (bypass, reimplantation).

Aortic-related reintervention included all secondary interventions related to the initial procedure or to the graft and its TVs for both groups during follow-up, as defined by the reporting standards.<sup>1</sup>

According to these reporting standards, clinical failure is a composite endpoint defined as death from complications of the initial operation or a secondary intervention, aortic aneurysm rupture, aortic conversion to OSR, persistent type I or III EL, sac expansion  $>5$  mm, device migration  $>10$ mm, infection or thrombosis in the F-BEVAR group and aneurysm-death, graft infection or thrombosis or para-anastomotic aneurysm in the open group. Specific endovascular outcomes of the F-BEVAR group were analyzed according to the current reporting standards.<sup>1</sup>

Proximal aorta degeneration was defined as a diameter increase  $\geq 5$  mm within 5 cm above the ostium of the more proximal TV for the endovascular group and 5 cm above the proximal anastomosis for the open group. Access-related complications during follow-up included any pseudoaneurysm, hematoma, thrombosis, or unplanned reintervention for the endovascular group and incisional hernia (IH) or bulging abdominal wall for the open group. Hospitalizations for bowel occlusion were collected.

### Statistical Analysis

Patients in the open surgery group were propensity-score matched to patients in the endovascular group. In calculating the propensity score, prespecified sets of covariates (age, sex, aneurysm diameter, clamp level, previous aortic surgery, coronary artery disease, chronic obstructive pulmonary disease, CKD [determined by serum creatinine level], diabetes mellitus, and smoking) were included as confounders in a logistic regression model. Anatomical classification was not included in the covariates because for the same disease extent, the aortic segment to be replaced may differ according to the choice of OSR vs F-BEVAR.<sup>1</sup>

The logistic regression model was used to generate the score and a score-based-matched control group using a caliper method with a threshold of 2 standard deviations of the difference in propensity score. The propensity-score-matched analysis is detailed in the previously published analysis.<sup>3</sup> Mean and median with their standard deviation, and interquartile range were used to describe quantitative variables; absolute and relative frequencies to report qualitative ones. The mean follow-up index (FUI) was the ratio between the investigated follow-up period and the theoretically possible follow-up period up to the study end date (January 31, 2021). Death, reintervention, and renal function decline during follow-up were analyzed by means of Kaplan-Meier curves. The log-rank test was used to assess differences between F-BEVAR and OSR groups in the propensity-score-matched cohorts. A stratified analysis on renal decline was also performed according to the presence of AKI. Furthermore, a stepwise backward cox regression analysis was performed to investigate the relationship between time to renal decline and age, sex, presence of AKI, duration of the intervention and, only for OSR group, clamp level and duration, visceral repair and organ protection. Proportional-hazards assumption was tested on the basis of Schoenfeld residuals after fitting the model. The difference in the frequency of secondary endpoints between the 2 propensity-score-matched groups was assessed through the chi-square test or Fisher exact test. Patients died during the in-hospital stay were excluded from the long-term analysis. Similarly, patients who were discharged from the hospital with renal failure requiring permanent dialysis, were excluded from analysis of renal function decline. The *p* value was set at 0.05 and Stata 14 and SPSS 22 were used to perform the analysis.

## Results

### Demographics

During the study period, 281 procedures for c-AAA were identified. A total of 157 patients underwent F-BEVAR treatment; 119 patients underwent OSR. After 1:1 propensity-score matching, there were 102 patients in the F-BEVAR group and 102 patients in the OSR group. Demographics characteristics are reported in Table 1 and detailed in a previously published analysis.<sup>3</sup>

### Procedure Data and Perioperative Results

In the matched endovascular group, the mean operative time was  $160.9 \pm 65.3$  minutes. The total volume of contrast agent averaged  $108.8 \pm 42.6$  mL, fluoroscopy time averaged  $31.8 \pm 22.3$  minutes, and indirect dose-area product averaged  $57.84 \pm 39.4$  Gy/cm<sup>2</sup>. Technical success was achieved in 102 patients (100%). There were 255 renal and

**Table 1.** Clinical and Demographic Features.

	OSR (n = 102)	F-BEVAR (n = 102)	<i>p</i>
Age, years, mean (SD)	71.7 (7.0)	71.8 (8.0)	0.96
Male	94 (92.2)	97 (95.1)	0.39
Coronary Artery Disease	39 (38.2)	43 (42.2)	0.57
Chronic Obstructive Pulmonary Disease	39 (38.2)	41 (40.2)	0.77
Chronic Kidney Disease	28 (27.5)	25 (24.5)	0.63
Diabetes Mellitus	12 (11.8)	13 (12.7)	0.83
Smoking	35 (34.3)	30 (29.4)	0.45
Aneurysm diameter, mm, mean (SD)	60.6 (9.3)	59.8 (8.8)	0.52
Previous aortic surgery	4 (3.9)	7 (3.9)	0.35

Abbreviations: F-BEVAR, fenestrated and branched endovascular aneurysm repair; OSR, open surgical repair; SD, standard deviation.

visceral arteries incorporated by 245 fenestrations as well as 10 branches, with a mean of 2.5 stented vessels per patient. In the OSR-matched group, the mean procedure and proximal aortic clamping times were  $311.4 \pm 81.4$  minutes and  $27.5 \pm 8.3$  minutes, respectively. The surgical approach was retroperitoneal in 89 (87.3%) patients and transperitoneal in 13 (12.7%) patients. We performed 27 associated renal and visceral procedures in 21 patients (20.5%): 15 renal artery reimplantation (including polar renal arteries), 6 aortorenal bypasses, 2 aorto-visceral bypasses (superior mesenteric artery and common hepatic artery), 2 renal angioplasties (inclusive proximal anastomosis with a beveled graft), and 2 renal transaortic endarterectomies. When renal artery direct reimplantation or bypass was performed, selective perfusion of the renal arteries was achieved with infusion of a cold renal perfusion (lactated Ringer solution and mannitol 10%). Intensive care unit stay was similar in both groups with a median of 1 day (range, 0-286 days and 1-11 days for the F-BEVAR and OSR groups, respectively; *p*=0.33). Perioperative outcomes are reported in Table 2.

### Long-Term Results

The matched population had a median follow-up of 67 months (Q1 46, Q3 88) and mean FUI of 0.69. Long-term clinical outcomes are reported in Table 3.

In the matched cohort, 78 deaths (38.2%) were observed during follow-up. The mortality was similar between groups (40.2% vs 36.3% in the F-BEVAR and OSR groups, respectively) with no significance differences. The Kaplan-Meier estimated overall survival at 24 months was 86.9% and 89.0%, respectively. It was 77.1% and 84.0% at 48 months, 66.1% and 70.8% at 72 months, respectively (*p*=0.40).



**Table 2.** Characteristics and Perioperative Outcomes.

	OSR (n = 102)	F-BEVAR (n = 102)	p
Anatomical classification			
Juxtarenal	32 (31.4)	36 (35.3)	0.65
Pararenal	49 (48.0)	53 (52.0)	0.67
Paravisceral	16 (15.7)	10 (9.8)	0.29
Type IV TAAA	5 (4.9)	3 (2.9)	0.72
Clamp level			
Supra-renal/1 or 2 fen.	57 (55.9)	48 (47.1)	.26
Suprarenal/3 or 4 fen.	45 (44.1)	54 (52.9)	.21
Thirty-day mortality	2 (2.0)	3 (2.9)	.68
In-hospital mortality	3 (2.9)	4 (3.9)	1
AKI	53 (52)	30 (19.6)	<b>&lt;.001</b>
Severe AKI	17 (16.7)	7 (6.9)	<b>.03</b>
Permanent dialysis	2 (2.0)	3 (2.9)	.68
Cardiac complications	6 (5.9)	4 (3.9)	.52
Pulmonary complications	6 (5.9)	6 (5.9)	1
Any complications	31 (30.4)	29 (28.4)	.63
Early reinterventions	4 (3.9)	12 (11.8)	<b>.04</b>

Data are presented as n (%) unless stated otherwise.

Abbreviations: AKI, acute kidney injury; F-BEVAR, fenestrated and branched endovascular aneurysm repair; fen, fenestrations; OSR, open surgical repair; TAAA, thoracoabdominal aortic aneurysm.

**Table 3.** Long-Term Outcomes Comparison of Open Surgical Repair (OSR) and Fenestrated and Branched Endovascular Aneurysm Repair (F-BEVAR) in the Matched Groups.

	OSR (n = 99)	F-BEVAR (n = 98)	p
Primary endpoints			
Overall mortality <sup>a</sup>	37 (36.3)	41 (40.2)	.40
Aneurysm-related mortality <sup>a</sup>	6 (5.8)	7 (6.8)	.30
Chronic renal decline <sup>b</sup>	46 (47.4)	27 (27.8)	<b>&lt;.01</b>
Secondary endpoints			
Aortic-related reintervention	5 (5.0)	23 (23.5)	<b>&lt;.01</b>
Target vessel occlusion	5 (5.0)	1 (1.0)	.21
Proximal aorta degeneration	12 (12.1)	4 (4.1)	<b>.04</b>
Access-related complications	22 (22.2)	8 (8.2)	<b>.01</b>
Graft infection	2 (2.0)	1 (1.0)	1
Clinical failure	5 (5.1)	12 (12.2)	.07

Data are presented as n (%) unless stated otherwise.

Abbreviations: F-BEVAR, fenestrated and branched endovascular aneurysm repair; OSR, open surgical repair.

<sup>a</sup>In-hospital death cases were included in the analysis. Percentages were calculated on 102 and 102 patients for the OSR and F-BEVAR group, respectively.

<sup>b</sup>The chronic renal decline analysis excluded patients with permanent dialysis after OSR (n = 2) and F-BEVAR (n = 1) group. Percentages were calculated on 97 and 97 patients for the OSR and F-BEVAR group, respectively.

Thirteen (6.4%) aneurysm-related deaths were observed in the total cohort, 7 (6.8%) and 6 (5.8%) in the F-BEVAR

and OSR groups, respectively. Three in each group (3%) during long-term follow-up: In the F-BEVAR group, the cause of aortic death was aortic aneurysm rupture, stent-graft thrombosis, and graft infection. In the OSR group, the cause of death was graft infection in 2 cases, and iliac pseudoaneurysm rupture in 1 case. The Kaplan-Meier survival estimated freedom from aneurysm-related death rates were 97.9% and 99% following F-BEVAR and OSR groups, at 24 and 48 months, respectively. At 72 months, it was 96.4% and 99%, respectively (p=0.30) (Figure 1).

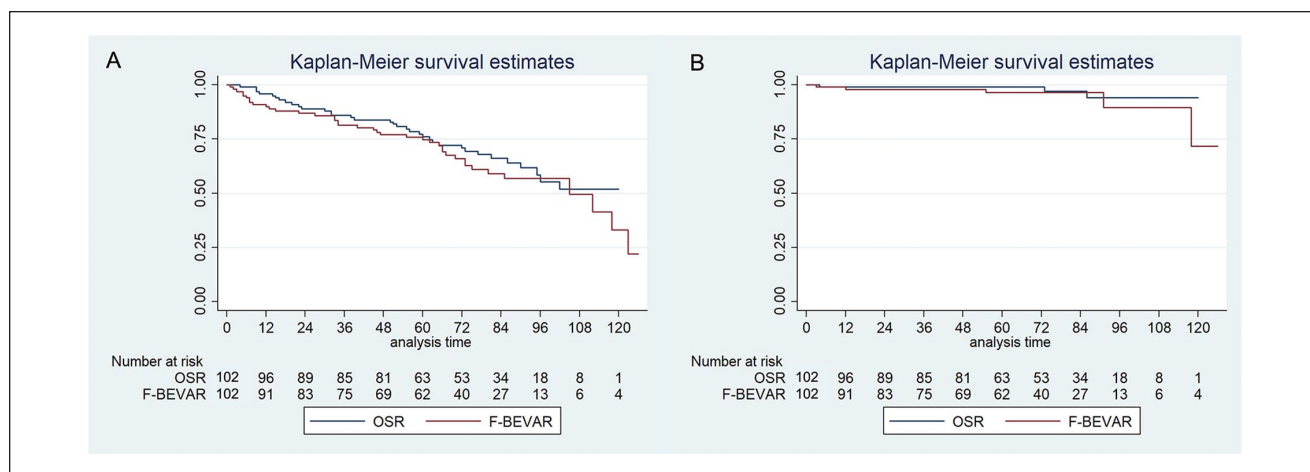
After exclusion of in-hospital death cases, a total of 197 matched patients were analyzed in the long term. There were 98 patients in the F-BEVAR group and 99 patients in the OSR group. The CRD analysis excluded 2 and 3 patients with permanent dialysis after OSR and F-BEVAR, respectively.

During follow-up, late renal function decline occurred in 27 (27.8%) vs 46 patients (47.4%) in the F-BEVAR and OSR groups, respectively (p<0.01). In patients with AKI, 45.0% (9/20) and 64.1% (34/53) developed CRD in the F-BEVAR and OSR groups, respectively. No new cases of dialysis were observed during follow-up in both groups (Figure 2A).

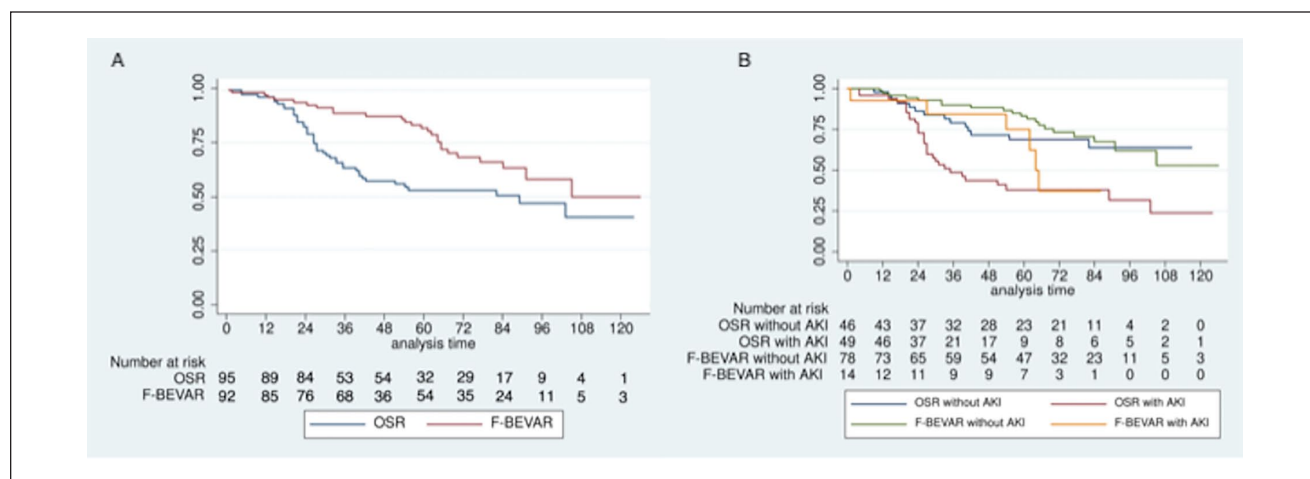
The Kaplan-Meier analysis demonstrated that, in both groups, patients without postoperative AKI had a significantly higher freedom from CRD at 24 months (93% in F-BEVAR and 86.4% in OSR) compared with patients with postoperative AKI (92.9% in F-BEVAR and 72.8% in OSR). Estimated freedom from CRD at 48 months was 88.5% and 71.7% in F-BEVAR and OSR groups in patients without AKI, and 84.4% and 43.9% in patients with AKI; at 72 months, 73.2% and 68.8% in F-BEVAR and OSR patients without AKI and 37.5% and 38.2% in F-BEVAR and OSR patients with AKI (p<0.001) (Figure 2B).

The multivariate Cox proportional hazards analysis demonstrated that age (hazard ratio [HR], 1.06; 95% confidence interval [CI], 1.01–1.13; p=0.03) and postoperative AKI (HR, 2.60; 95% CI, 1.01–6.35; p=0.04) were identified as risk factors for CRD in the F-BEVAR group. Age (HR, 1.05; 95% CI, 1.01–1.10; p=0.02), clamping time >30 minutes (HR, .96; 95% CI, .93–.99; p=0.03), and postoperative AKI (HR, 2.99; 95% CI, 1.57–5.73; p<0.01) were identified as risk factors for CRD in the OSR group.

During follow-up, 23 aneurysm-related reinterventions (23.5%) were performed in the F-BEVAR group, and 5 (5.1%) in the OSR group (p<.01). In the F-BEVAR group, 5 patients were treated for type Ib EL with iliac extension cuffs, 4 patients underwent embolization of a type II EL, 1 for concomitant type Ib and type II ELs, and 1 for concomitant type Ia and III ELs. There were 7 procedures performed for TV relining: 2 type III EL and 5 TV stenosis (4 SMAs and 1 renal artery) (Figure 3). Two SMA stenosis presented chronic mesenteric ischemia. Other causes of reinterventions were acute limb ischemia (n=4) and graft infection



**Figure 1.** Cumulative Kaplan-Meier estimate of overall death (A) and aneurysm-related death (B) of fenestrated and branched endovascular aneurysm repair (F-BEVAR) or open surgical repair (OSR) for complex abdominal aortic aneurysms.



**Figure 2.** Cumulative Kaplan-Meier estimate of chronic renal decline after fenestrated and branched endovascular aneurysm repair (F-BEVAR) or open surgical repair (OSR) for complex abdominal aortic aneurysms (A). Cumulative Kaplan-Meier estimate of chronic renal decline after F-BEVAR) or OSR depending on the presence of acute kidney injury after the treatment (B). AKI, acute kidney injury.

(n=1). Two patients with IA EL rejected further treatment. In the OSR group, 4 patients required endovascular exclusion of distal aortic anastomotic pseudoaneurysms, and 1 patient underwent reintervention for graft infection. Rates of freedom from reintervention were 93.4% vs 99% at 24 months, 83% vs 99% at 48 months, and 70.4% vs 94.1% at 72 months, in the F-BEVAR and OSR groups, respectively ( $p<0.01$ ) (Figure 4).

Long-term clinical failure was observed in 12 (12.2%) vs 5 patients (5.1%) in the F-BEVAR and OSR groups, respectively ( $p=0.07$ ). Specific complications occurring in the F-BEVAR group are reported in Table 4.

During follow-up, 1 TV (renal artery) occluded in the F-BEVAR group and 5 in the OSR group (2 renal bypass, 1

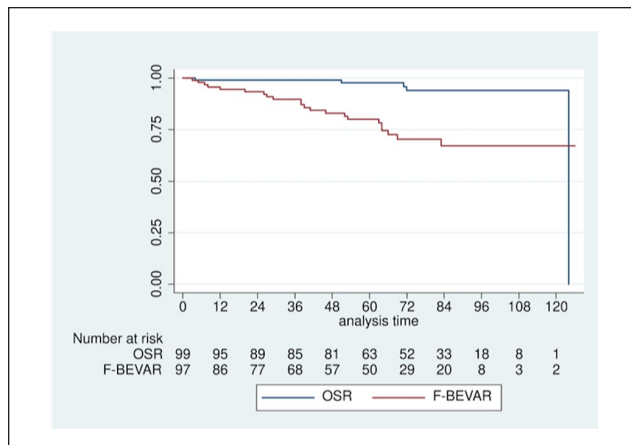
native renal artery, and 2 polar renal artery reimplantation) ( $p=1.0$ ).

Proximal aortic degeneration was observed in 4 patients (4.1%) vs 12 (12.1%) ( $P = .04$ ) in the F-BEVAR and OSR groups, respectively. No cases of proximal aortic degeneration had a new aortic indication of treatment.

Access-related complications occurred in 8 (8.1%) vs 22 (22.2%) patients ( $p=0.01$ ) in the F-BEVAR and OSR groups, respectively. Four cases of femoral hematoma drainage, 3 cases of seroma, and 1 case of surgical arteriovenous fistula were observed in the F-BEVAR group; 9 cases of IH and 16 cases of abdominal bulging wall (Figure 5), of whom 3 with concomitant presence of the 2 complications, were present in the OSR group. None of these cases of IH and abdominal



**Figure 3.** Superior mesenteric artery stenosis during follow-up after fenestrated and branched endovascular aneurysm repair (F-BEVAR).



**Figure 4.** Cumulative Kaplan-Meier estimate of reintervention after fenestrated and branched endovascular aneurysm repair (F-BEVAR) or open surgical repair (OSR) for complex abdominal aortic aneurysms.

bulging wall had indication for treatment. No case of hospitalization for bowel obstruction was observed in both groups.

## Discussion

F-BEVAR is increasingly implemented to manage complex aneurysm with challenging necks and involvement of renal and visceral arteries. Although early and mid-term results of

**Table 4.** Long-Term Specific Outcomes of the F-BEVAR Group.

	N=98
Shrinkage	52 (53.1)
Stable sac	34 (34.7)
Aneurysm growth $\geq 5$ mm	12 (12.2)
EL	23 (23.5)
Types I to III	11
Type II	12
Target vessel occlusion	1 (1.0)
Reintervention target vessel	7 (7.1)
Limb occlusion	4 (4.1)
Graft instability	16 (16.3)
Target vessel instability	19 (19.3)

Data are presented as n (%) unless stated otherwise.

Abbreviation: EL, endoleak.



**Figure 5.** Abdominal bulging wall during follow-up after open surgery repair.

this approach exhibited favorable results compared with OSR, long-term outcomes are less well studied, and concerns may rise in terms of durability of the repair, risk of reinterventions and late CRD. In the absence of randomized trials, practices are heavily reliant on individual expert preferences and competences.

This study provides comparative long-term results in a matched population of patients with c-AAA treated in centers with mature experience with a median follow-up >5 years.

In our study, no significant difference in overall long-term and aneurysm-related mortality, between F-BEVAR and OSR was observed. Fiorucci et al<sup>15</sup> showed similar survival rates in the matched c-AAA F-BEVAR and OSR groups at 3 years, with absence of aneurysm-related deaths. A recent meta-analysis published by Antoniou et al,<sup>16</sup> including 11

observational propensity-score-matched studies, demonstrated a statistically nonsignificant medium-term survival benefit for open surgery, explained by different patient selections.

The similar long-term mortality rate of these 2 techniques confirms that the higher rate of reintervention after F-BEVAR does not affect long-term survival, as previously reported.<sup>17</sup> Indeed, the main concern regarding F-BEVAR long-term durability is related to the rate of reinterventions due to ELs, bridging stents and stent-graft instability. We observed a significantly higher rate of reinterventions in the F-BEVAR group (23.5% vs 5.1%,  $p < 0.01$ ), with 7.1% and 16.3% rate of TVs and stent-graft instability, respectively. These outcomes are confirmed by others reports. In their systematic review, Rao et al<sup>18</sup> found a significantly higher rate of reintervention after F-BEVAR of juxtarenal-AAA (jr-AAA) compared with OSR (12.7% vs 4.9%,  $p < 0.001$ ). Fiorucci et al<sup>15</sup> demonstrated a higher 4-year freedom from reintervention in the OSR group (95.6% vs 77.8%,  $p = 0.01$ ). In our series, the most common indications for reintervention in the F-BEVAR group were type Ib ELs, type II ELs, and bridging stent relining for stenosis. Five patients were treated for significant visceral stenosis, of whom 4 (4.1%) of SMA. In our study, the rate of SMA restenosis is in line with the current literature.<sup>19</sup> Although there was no significant difference ( $p = 0.08$ ), we observed a lower rate of TVs occlusion in the F-BEVAR group with only 1 case of renal artery occlusion.

Most of the reinterventions in the F-BEVAR group were endovascular procedures. Although our results showed that the higher rate of reinterventions after F-BEVAR had no impact on long-term survival, it also highlighted the pivotal role of surveillance imaging and reinterventions in the maintenance of F-BEVAR durability. The stricter imaging surveillance in the F-BEVAR group might explain the lower rate of occlusion in this group, since prompt diagnosis allowed treatment of stenosis before occlusion.

A non-significant higher rate of long-term clinical failure in the F-BEVAR group was observed compared with OSR, 12 vs 5 ( $p = 0.07$ ), probably because of the 12.2% rate of sac enlargement in the F-BEVAR group. Li et al<sup>20</sup> showed that sac regression was associated with a significant survival advantage and can be used as a clinical marker for success after fenestrated endovascular aortic repair (FEVAR). Further investigations and longer follow-up are needed to clarify the very long-term impact of sac enlargement after F-BEVAR.

Renal impairment is a critical issue after OSR for c-AAA. It has been already reported that AKI was higher after c-AAA OSR compared with F-BEVAR.<sup>21</sup> In line with this evidence, we found a significantly higher rate of AKI in the OSR group (19.6% vs 52%;  $p < 0.001$ ). However, no previous comparison of long-term CRD after OSR and F-BEVAR performed for c-AAA has been reported. In our series, OSR was associated with a significantly higher rate

of late CRD compared with F-BEVAR (47.4% vs 27.8%,  $p < 0.01$ ), but no cases of new dialysis following aortic repair were registered in both groups. AKI and age were strong predictors of CRD after both OSR and F-BEVAR, and clamp time  $> 30$  minutes was a significant predictor for CRD after OSR. The high rate of supravisceral clamping (41.2%) and renal revascularization procedures (22.7%) performed in this series, and the high rate of postoperative AKI (52%), might explain the worst fate of long-term renal function after OSR. Sugimoto et al<sup>7</sup> reported a rate of CRD of 15.9% after OSR of 111 jr-AAA and pararenal-AAA during a mean follow-up of 24.5 months. Notably, in their series, the rate of supravisceral clamping was low, 5.6%, and only 13% of the patients underwent renal artery-associated procedures. Chaufour et al<sup>5</sup> analyzed outcomes of 315 consecutive jr-AAA OSR and reported a low rate of CRD (7.9%) during a mean follow-up of 4.3 years; AKI was the strongest predictor of CRD, followed by diabetes and pre-operative CKD. Tran et al<sup>22</sup> performed 110 FEVAR for jr-AAA and c-AAA, and they reported 26.2% of CRD during a mean follow-up of 11.7 months. They also found age as the strongest predictor of CRD. Because CRD significantly impacts the patient's quality of life and life expectancy, it is mandatory to evaluate patient's specific pre-operative risk of AKI, considering both his comorbidities and the type of repair.<sup>23,24</sup> One of the main differences between OSR and F-BEVAR is the relative risk of AKI associated with the proximal level of repair. Following F-BEVAR, the risk is similar regardless of the number of visceral arteries involved in the repair,<sup>25</sup> but following OSR, it is correlated with clamp level, clamp time, and need for renal/visceral revascularization procedures.<sup>26,27</sup>

One of the differences between OSR and F-BEVAR is that the latter requires longer aortic coverage to achieve a durable sealing. In the case of c-AAA, the evolution in endograft design and planning has trended from 2 fenestration designs to 3/4 fenestrations, providing long and stable platforms for proximal fixation and seal.<sup>28</sup> Although this could theoretically increase the risk of spinal cord injury (SCI), which is not supported by published data, it might also have a protective effect on aortic enlargement, or significantly reduce the rate of type Ia ELs if the sealing zone is located above the CT. Nevertheless, 55.9% of 1/2 fenestrations, in this series, we had no case of SCI in both groups, and we found a significant higher rate of proximal aortic degeneration in the OSR group ( $p = 0.04$ ). However, no patient required further proximal aortic treatment.

Notably, a higher significant rate of access-related complications was observed in the OSR group (22.2% vs 8.1%,  $p = 0.01$ ). We observed 9 cases (9.1%) of IH. A recent meta-analysis showed that the prevalence of IH after open abdominal aortic aneurysm repair is high, ranging from 11% to 36%. There is no evidence to suggest that a retroperitoneal approach reduces the risk of IH.<sup>29</sup> In our



experience, the retroperitoneal approach was preferred because it provided optimal exposure of proximal visceral aorta.<sup>5</sup> Nevertheless, in our series it was associated with a high rate of abdominal bulging wall (16.2%) without necessity of reintervention.

### Study Limitations

The propensity-score-matched analysis did not allow a completely balanced comparison and residual confounding due to unmeasured confounders could not be ruled out. The retrospective analysis was only in part balanced by prospective data collection. Furthermore, this study showed the one experienced surgeon result in each group, and this may be a limitation for reproducibility in larger group of operators.

### Conclusions

This study describes the long-term outcomes of a matched populations of patients with c-AAA following F-BEVAR and OSR. Similar mortality and aneurysm-related mortality rates were observed. The F-BEVAR group presented a higher rate of reinterventions; CRD was significantly higher in OSR group and correlated with postoperative AKI. These long-term results reflect the outcomes of a complex procedure performed by a single experienced operator in 2 high-volume centers, and followed with a strict surveillance imaging follow-up.

### Declaration of Conflicting Interests

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